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Applied Acoustics 65 (2004) 229–241
applied acoustics
www.elsevier.com/locate/apacoust

The benefit of practice for sound localization without sight

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Received 10 February 2003; received in revised form 16 September 2003; accepted 10 October 2003

Abstract

An experiment was designed to determine whether normally sighted human subjects would be able to adapt to the handicapping effects of sudden deprivation of visual cues on horizontal plane sound localization. Two groups of sighted normal-hearing young adults participated. One group was allowed the benefit of sight. The other group was blindfolded. Measurements of accuracy and the time to respond were made daily over the course of five consecutive days, in a semi-reverberant sound proof booth that modeled listening in a small office. Sound localization was assessed using an array of eight speakers that surrounded the subject in space. Each day, one block of 120 trials was presented for each of three stimuli, two one-third octave noise bands, centred at 0.5 and 4 kHz, and broadband noise, to assess the utilization of interaural temporal difference cues, interaural level difference cues and binaural and spectral cues in combination. Blindfolded subjects were relatively less accurate than sighted subjects. Both groups showed gains with practice, the blindfolded group to a greater degree, largely due to improvements in the use of spectral cues. The blindfolded group took longer to respond than the sighted group, but showed greater decrements in response time with practice.
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Keywords: Sound localization; Practice effects; Blindness

1. Introduction

The purpose of this study was to investigate the benefit of practice for sound localization in blindfolded sighted subjects. This research was undertaken to

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doi:10.1016/j.apacoust.2003.10.003

determine the adaptability of human subjects to temporary blindness. Previous research has demonstrated that the blindfolding of normally sighted subjects results in deficits in accuracy in horizontal plane sound localization [1]. Observed outcomes were comparable to those of subjects who had become blind at an early age and had no visual experience of spatial location. The results of both groups were in contrast to those of subjects with late onset blindness whose performance was similar to or better than that of sighted subjects. The difference between the late blind and blindfolded sighted subjects pointed to the debilitating effect of sudden loss of sight and suggested the potential for re-instatement of sound localization with practice.

Previous studies of sound localization in both human subjects and animal models provide evidence for perceptual learning, i.e., an improvement in performance with practice [2]. Hofman et al. [3], for example, measured accuracy in sound localization in adult human subjects who had custom molds fitted within the conchas of both ears for periods of up to 6 weeks. The stimulus, a one-half second broadband white noise, was presented within a two-dimensional occulomotor range of ± 30 deg in azimuth or elevation. The response was a saccadic eye movement. Azimuthal accuracy was not affected by the ear molds. Errors in elevation discrimination diminished over time. Failure to demonstrate an effect in the horizontal plane may have been due to the use of a speaker array which did not allow for study of front/back confusions. In a more recent study, King et al. [4] explored adaptation to altered sound localization cues, introduced at birth or later in life. In this study, unlike that of Hofman et al. [3], ferrets were trained to ambulate to sound sources that surrounded them in space. In one group, in which one ear was plugged at birth, accuracy in sound localization in adulthood was no different than that of normally reared ferrets. A second group, in which one ear was plugged in adulthood, was able to correct for initial decrements in performance, with practice. These results are particularly noteworthy because they clearly document the capacity for adaptation to altered auditory input by the mature brain.

The current study was conducted to determine whether normally sighted human subjects would be able to adapt to the handicapping effects of sudden deprivation of vision on horizontal plane sound localization [1], and whether such adaptation would be specific to one or more of the binaural and spectral cues normally used for horizontal plane sound localization [5]. Measurements of accuracy in sound localization and the time to respond were made daily over the course of a week. The two measures were included as a possible means of discriminating between learning due to changes in sensory encoding and non sensory decision-making [6,7]. A comparison of the effect of practice on the rate of change in accuracy and the time to respond was made between normally sighted subjects who were allowed to see the speakers to be localized and those who were blindfolded. The goal was to provide new information on the ability to use auditory cues to localize hazard in situations where vision is temporarily obscured. Examples include fire fighting and military land operations where smoke, fog or fumes may obstruct vision. In these situations errors in sound localization could result in fatalities.

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2. Experimental design

Two groups of 10 human subjects with normal hearing and normal or corrected vision were tested. The study was open to adults ranging in age from 18 to 35 years. Previous studies have demonstrated that, even with normal hearing, subjects' accuracy in sound localization decreases with aging, beginning in the mid-30s [8]. One group (B) was tested with a blindfold to model the condition of recent blindness. The other group (S) was tested without a blindfold. For the first group, the blindfold was applied before the subjects entered the test chamber, so that they would not have an opportunity to view the room or speaker array. Subjects in the second group had the benefit of sight upon entry.

Subjects were tested individually once each day over the course of a 5-day week, while seated in the centre of a semi-reverberant sound proof booth that modeled real-world listening in a small office [9]. Sound localization was assessed using a circular array of eight loudspeakers surrounding the subject in the horizontal plane at a distance of 1 m from the subject's centre head position (see Fig. 1). Two speakers were placed in each of the four spatial quadrants, at azimuth angles of 15° on either side of the midline axis, front and back, and at azimuth angles of 15° in front of and behind the interaural axis, on the right and left. The eight azimuth angles were 15°, 75°, 105°, 165°, 195° (−165°), 255° (−105°), 285° (−75°), and 345° (−15°). These were chosen to be right/left and front/back symmetric.

Accuracy in sound localization and the time to respond were measured for two one-third octave noise bands, centred at 0.5 and 4 kHz, and broadband noise. The two one-third octave noise bands allowed an independent evaluation of the utiliza-

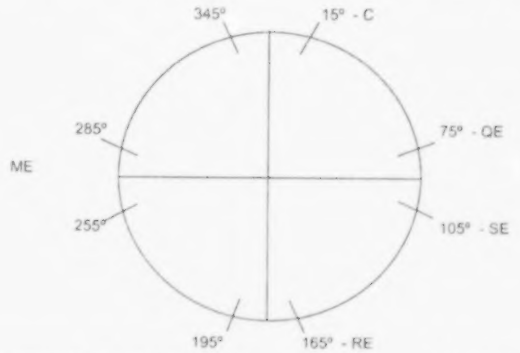

Fig. 1. A schematic of the 8 speaker array. The abbreviations C (correct response), RE (front/back mirror image reversal error), QE (within-quadrant error), SE (same side error other than RE or QE), and ME (error on the wrong side of midline) exemplify correct response and error types for the 15 degree azimuth angle (see Section 4).

tion of primarily interaural temporal difference (0.5 kHz) versus primarily interaural level difference cues (4 kHz). The broadband noise tested the use of binaural and spectral cues in combination [5,10]. Stimuli were 300 ms in duration (including a linear rise/decay time of 50 ms) and were presented at a comfortable listening level of 75 dB SPL. Subjects were given feedback about the correctness of their judgments. Response time was measured covertly, so as not to affect accuracy [11,12].

3. Methods and materials

3.1. Subjects

The subjects for the study were recruited by sending an email to employees of Defence Research and Development Canada-Toronto. Twenty male and female volunteers aged 19–33 years were randomly assigned to the two groups. Prior to inclusion in the study, subjects were screened for a history of head injury and severe systemic disease, factors that may affect sustained attention and concentration during performance of the test protocols. Only right-handed subjects were included in this study due to the possible confounding effect of cerebral hemisphere dominance for processing spatial information [13]. If all of these criteria were met, the subjects underwent a hearing screening test. Only those with hearing thresholds better than 20 dB HL in each ear at 0.5, 1, 2 and 4 kHz, and an interaural difference in threshold no greater than 10 dB at these pure-tone frequencies were admissible [14].

3.2. Apparatus

The test facility was a double-walled semi-reverberant sound proof booth (IAC Series 1200) with inner dimensions of 3.5 (L)×2.7 (W)×2.3 (H) metres. Reverberation times were 0.6 s at 0.125 and 0.25 kHz, 0.4 s from 0.5 to 4 kHz, and 0.3 s at 6.3 and 8 kHz. Ambient noise in the booth was less than the maximum allowed for audiometric testing [15]. The stimuli to be localized were generated by a noise generator (Bruel & Kjaer Type 1405) and one-third octave bandpass filter (Bruel & Kjaer Type 1617). Stimulus envelope shape and duration and trial by trial loudspeaker selection were controlled by a Coulbourn Instruments modular system. Level was specified using a programmable attenuator (Coulbourn S85-08) and a set of integrated stereo amplifiers (Realistic SA-150). The stimuli were presented by a set of eight loudspeakers (Radio Shack Minimus 3.5) closely balanced with respect to output levels (1.5 dB) and frequency response from 0.125 to 12 kHz (2.5 dB). Detailed descriptions of the booth, instrumentation and calibration methods for the sound localization test have been published previously [8,9]. Subjects signified their spatial judgments by means of a specially designed laptop response box with a set of eight microswitches in the same configuration as the speaker array, both in number of elements and azimuth angles. The microswitches were capped with hard silicon bumps obtained from the Canadian National Institute for the Blind to help the blindfolded subjects locate them more easily.

3.3. Procedure

At the start of the experiment, the experimenter assisted in positioning the head to face the straight ahead 0° azimuth angle position. An adjustable head rest with the dimensions of 20 cm (W) by 14 cm (H) attached to the back of the subject's chair aided in maintaining the alignment between the speaker array and the interaural axis of the head. The head rest was considered small enough not to modify the spectral content of the stimuli. Subjects were instructed to sit squarely and try to minimize head movement (a possible confounding variable) during each trial. Head movement may help to resolve front/back confusions [16]. They were also advised to use both hands for responding. When testing the blindfolded subjects, the experimenter positioned the right and left hands over the response keys on the right and left sides of the box. One set of practice trials consisting of one presentation of the broadband stimulus through each loudspeaker with feedback was then given to provide the subject with a spatial sense of the speaker array relative to the response buttons, and to ensure that the instructions were understood.

Each subject participated in one test session per day for five consecutive days. A session lasted approximately 30 min. During each session, one block of forced-choice speaker identification trials was given for each of the three stimuli. The broadband noise stimulus was presented first, followed by the two narrowband stimuli in random order, to maximize learning to map the speaker array on the response keys. Previous studies have shown that subjects are most accurate when localizing broadband noise [8]. A trial block comprised 15 random presentations of the stimulus through each of the speakers, giving a total of 120 trials. Choice of number of trials/speaker was based on the need to balance any initial learning and possible fatigue [17]. The rate of presentation of trials was approximately one every seven seconds. Following each stimulus presentation, subjects were required to push the microswitch corresponding to the loudspeaker that emitted the stimulus. Guessing, if uncertain, was encouraged. The time to respond on each trial was measured covertly, so as not to affect accuracy. At the end of each block of trials subjects were told their percentage correct.

4. Results

The percent correct sound localization judgments and the median response time for correct trials were calculated for each block of trials. The median response time was chosen in preference to the mean because of the previously demonstrated skewness in response time data [18]. The effects of availability of sight, stimulus frequency, and practice were evaluated using repeated measures analyses of variance, ANOVAs [19]. All statistical analyses were performed using SPSS computer software.

4.1. Accuracy in sound localization

Table 1 shows the mean percent correct, P(C), sound localization judgements for the 10 subjects in each group, for combinations of stimulus and replication. A

Table 1
Overall P(C) in sound localization for the two groups (effects of stimulus and replication)

Group	N	Rep	Frequency		
			0.5 kHz	4 kHz	Broadband
Sighted	10	1	51.7 (10.4)[a]	64.3 (18.8)	85.5 (8.0)
		2	52.4 (9.3)	73.5 (14.2)	85.7 (7.3)
		3	49.2 (9.4)	74.5 (16.0)	84.3 (6.7)
		4	51.9 (11.0)	71.7 (19.3)	86.0 (7.1)
		5	54.2 (8.8)	74.6 (15.8)	84.7 (8.9)
Blindfolded	10	1	46.7 (10.2)	53.2 (15.5)	71.6 (17.6)
		2	45.2 (7.8)	62.3 (16.6)	81.6 (10.3)
		3	46.3 (7.9)	59.3 (15.4)	81.3 (10.7)
		4	47.4 (11.6)	65.1 (19.2)	87.0 (9.9)
		5	49.5 (10.5)	67.2 (20.5)	85.9 (9.6)

[a] Mean (S.D.).

repeated measures ANOVA applied to these data indicated that there were significant effects of stimulus, replication, replication by group, stimulus by replication, and stimulus by replication by group ($P < 0.025$ or better). Subjects in both groups showed the greatest accuracy for the broadband noise stimulus (83.4%, averaged across groups and replications) and the least accuracy for the 0.5 kHz stimulus (49.5%). Both groups also displayed an improvement over the five replications. Paired t-tests for the first and last replications indicated that the sighted group improved significantly by 10.3% ($P < 0.005$) for the 4 kHz stimulus. The blindfolded group improved significantly by 14.0 and 13.5% ($P < 0.01$ or better) for the 4 kHz and broadband stimuli, respectively. In thirteen of fifteen stimulus by replication conditions, P(C) was relatively lower for the blindfolded than sighted group. However, between group t-tests on the P(C)s observed for the two groups at the first and fifth replications indicated that there was a significant difference in accuracy (14%) only at the first replication, in the case of the broadband noise ($P < 0.05$). By the fifth replication, there was virtually no difference between the two groups. Non-significant differences for the 0.5 and 4 kHz stimuli ranged from 5 to 11%.

To determine whether the spatial quadrant from which the stimuli originated was a significant determinate of performance, accuracy scores were calculated separately for the four spatial quadrants. Responses were scored as correct, as long as the quadrant: front left (FL), front right (FR), back left (BL), or back right (BR) was correctly identified, regardless of whether the particular loudspeaker azimuth was also correct. Fig. 2 shows the mean quadrant percent correct for the two groups for each of the three stimuli, respectively. A repeated measures ANOVA on these data showed significant effects of stimulus, quadrant, replication, stimulus by replication, quadrant by replication, stimulus by quadrant by replication, and stimulus by quadrant by replication by group ($P < 0.05$ or better). For the sighted group, for the two narrowband stimuli, P(C) was higher on the left than right for both the front and back quadrants while for the broadband noise, P(C) was higher for the front than back quadrants. Regardless of the stimulus, accuracy was consistently

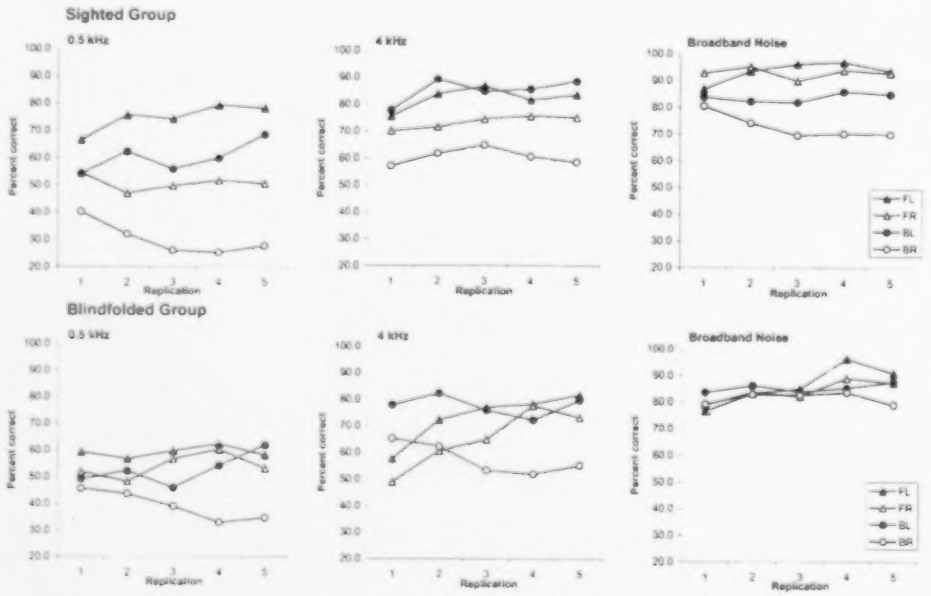

Fig. 2. The effect of stimulus and replication on the mean percent correct for each of the four spatial quadrants: FL (front left), FR (front right), BL (back left) and BR (back right), for the two groups.

poorest for the BR quadrant. For the blindfolded group, this pattern was beginning to emerge by the fifth replication.

Table 2 shows the mean percent correct observed for each of the eight loudspeaker azimuths for each of the three stimuli, averaged across replications. A repeated measures ANOVA applied to these data indicated that there were significant effects of stimulus, azimuth, replication, azimuth by group, azimuth by stimulus, replication by group, stimulus by replication, azimuth by replication, stimulus by replication by group, and stimulus by azimuth by replication ($P<0.04$ or better). For the 4 kHz and broadband stimuli, subjects in both groups were least accurate when the sound emanated from the speaker located at the 105° azimuth angle position (behind the ear on the right). For the 0.5 kHz stimulus, the sighted group had the greatest difficulty with the 105° azimuth angle and the blindfolded group with the 165° azimuth angle (the most rearward position on the right). Generally accuracy was higher at the corresponding azimuth angle positions on the left side compared with the right side, in line with the findings for overall P(C). Averaged across replications, the sighted group was relatively more accurate than the blindfolded group in eighteen of twenty-four stimulus by azimuth angle positions.

4.2. Erroneous responses in sound localization

Table 3 shows the distribution of errors for the sighted and blindfolded groups for each of the five replications by stimulus, averaged across azimuth. P(RE) is the mean percentage of front/back mirror image reversal errors, P(QE) is the mean percentage

Table 2
Azimuthal P(C) averaged across replications for the 0.5 kHz, 4 kHz and broadband noise stimuli for each of the two groups

Group	N	Azimuth (deg)	Frequency		
			0.5 kHz	4 kHz	Broadband
Sighted	10	15	34.4 (27.2)[a]	74.8 (35.6)	99.7 (0.85)
		75	63.9 (27.9)	69.6 (33.7)	86.0 (15.8)
		105	17.3 (20.2)	41.3 (27.1)	46.7 (22.1)
		165	36.5 (24.0)	65.7 (26.3)	96.7 (5.3)
		195	70.7 (27.2)	88.5 (9.5)	98.5 (1.9)
		255	44.7 (28.8)	72.4 (23.0)	68.1 (23.8)
		285	79.5 (23.1)	76.4 (31.3)	86.7 (10.7)
		345	68.0 (34.1)	85.1 (30.1)	99.5 (0.7)
Blindfolded	10	15	44.4 (30.7)	45.6 (33.8)	93.8 (7.6)
		75	56.8 (20.4)	62.5 (24.5)	69.2 (21.1)
		105	41.7 (20.3)	42.5 (24.7)	65.7 (26.7)
		165	24.1 (21.5)	57.6 (16.1)	87.7 (25.1)
		195	46.5 (28.8)	76.9 (20.6)	94.5 (7.8)
		255	49.7 (19.8)	62.7 (24.7)	72.1 (20.7)
		285	57.3 (24.3)	60.5 (22.9)	74.5 (10.9)
		345	55.5 (32.2)	81.7 (19.7)	94.0 (8.4)

[a] Mean (S.D.).

Table 3
The prevalence (%) of various error types in the two groups (effects of stimulus and replication)

Stimulus	Rep.	Group/error type							
		Sighted				Blindfolded			
		RE	QE	SE	ME	RE	QE	SE	ME
0.5 kHz	1	39.5 (6.2)[a]	2.3 (3.0)	2.8 (3.2)	3.7 (4.1)	37.0 (5.4)	5.1 (4.0)	6.1 (6.3)	5.2 (6.8)
	2	41.7 (6.3)	1.8 (2.6)	1.8 (2.8)	2.3 (2.1)	41.5 (6.9)	5.1 (4.5)	4.8 (4.6)	3.4 (3.2)
	3	42.4 (4.4)	2.3 (3.5)	2.2 (2.6)	3.9 (4.0)	41.0 (5.8)	4.1 (4.7)	4.3 (4.5)	4.3 (4.3)
	4	39.6 (8.2)	2.2 (2.8)	2.8 (3.2)	3.5 (4.4)	39.3 (5.6)	5.2 (6.2)	4.2 (3.7)	3.9 (4.3)
	5	39.0 (6.5)	2.2 (2.8)	2.2 (2.9)	2.5 (2.6)	39.8 (7.2)	2.6 (4.7)	3.9 (5.5)	4.2 (4.4)
4 kHz	1	22.1 (4.0)	6.3 (7.1)	4.8 (6.9)	2.5 (3.5)	27.3 (8.3)	9.3 (4.0)	6.9 (5.1)	3.3 (2.3)
	2	19.1 (9.2)	3.5 (3.7)	2.1 (2.6)	1.8 (3.1)	22.6 (8.0)	7.2 (5.6)	3.8 (3.8)	4.2 (5.9)
	3	16.8 (7.1)	3.7 (4.2)	2.6 (5.0)	2.4 (3.3)	22.6 (6.8)	8.5 (5.5)	4.8 (4.3)	4.8 (5.2)
	4	19.2 (7.5)	4.3 (6.9)	2.5 (6.0)	2.4 (3.2)	21.1 (10.4)	5.8 (4.5)	2.7 (3.5)	5.3 (6.1)
	5	18.1 (8.6)	2.4 (2.6)	2.2 (5.1)	2.7 (2.8)	20.1 (9.4)	5.3 (4.2)	3.4 (4.7)	4.0 (4.2)
Broadband	1	13.7 (7.1)	0.7 (1.1)	0.0 (0.0)	0.2 (0.3)	19.0 (8.8)	7.2 (7.5)	1.1 (2.6)	0.3 (0.4)
	2	13.3 (6.2)	0.8 (1.1)	0.0 (0.0)	0.3 (0.6)	15.7 (6.4)	2.6 (5.1)	0.0 (0.0)	0.2 (0.4)
	3	15.2 (6.3)	0.3 (0.6)	0.1 (0.3)	0.2 (0.3)	15.8 (8.0)	2.2 (4.1)	0.3 (1.0)	0.3 (0.8)
	4	12.8 (6.2)	0.8 (1.6)	0.3 (0.6)	0.1 (0.3)	11.3 (6.7)	1.7 (3.9)	0.0 (0.0)	0.0 (0.0)
	5	14.1 (7.8)	0.7 (1.1)	0.3 (0.6)	0.2 (0.4)	13.2 (8.4)	0.3 (0.7)	0.4 (1.3)	0.2 (0.3)

[a] Mean (S.D.); RE, front/back mirror image reversal error; QE, within-quadrant error; SE, within-side error other than RE and QE; and ME, opposite side error.

of within-quadrant errors, P(SE) is the mean percentage of errors other than an RE or QE on the correct side of the midline, and P(ME) is the mean percentage of errors involving the wrong side of the midline (see Fig. 1). For both groups, regardless of the stimulus, the greatest proportion of errors were front/back mirror image reversal errors. Averaged across groups and replications, these ranged from 14% for the broadband noise to 40% for the 0.5 kHz stimulus. Midline, side and quadrant confusions ranged from 1% for the broadband noise to 3% for the 0.5 kHz stimulus. At 0.5 kHz, there was relatively little change in the probability of each type of error across replications for either group. At 4 kHz, subjects in the sighted group showed a 4% decrease in P(RE) and P(QE) while the blindfolded group showed decreases of 7 and 4% for these two error types. For the broadband noise stimulus, the sighted group showed virtually no change in the percentage of each error type, while for the blindfolded group, P(RE) and P(QE) decreased by 6 and 7%, respectively.

4.3. Response time in sound localization

Fig. 3 and Table 4 show the mean of median correct response times (RT), as a function of replication by stimulus for each group. Standard deviations associated with the means ranged from 66.0 to 338.7 ms. They did not change monotonically with replication or stimulus but tended to be larger for the blindfolded than the sighted group, 229.4 vs. 135.4 ms, respectively. A repeated measures ANOVA applied to the RTs showed significant effects of group, stimulus, replication, stimu-

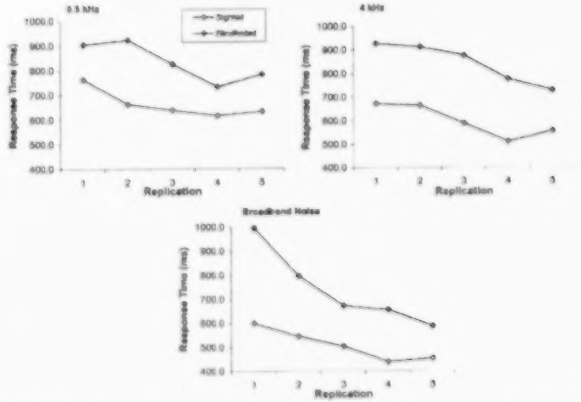

Fig. 3. The effect of stimulus and replication on the mean median correct response time for the two groups.

Table 4
Median RT in sound localization for the two groups

Group	N	Rep	Frequency		
			0.5 kHz	4 kHz	Broadband
Sighted	10	1	763.0 (183.0)[a]	672.7 (160.8)	599.3 (160.2)
		2	663.2 (101.7)	663.7 (143.4)	544.0 (95.5)
		3	637.7 (179.8)	587.5 (104.8)	501.7 (141.3)
		4	615.1 (173.4)	508.2 (66.0)	437.0 (83.8)
		5	631.2 (190.8)	552.5 (101.7)	451.1 (144.1)
Blindfolded	10	1	903.7 (275.5)	926.5 (246.5)	994.8 (267.7)
		2	922.3 (272.5)	911.3 (175.7)	795.5 (225.3)
		3	824.2 (338.7)	874.8 (217.1)	670.2 (222.7)
		4	732.3 (218.1)	773.4 (179.0)	651.4 (183.8)
		5	781.3 (195.8)	725.8 (256.0)	584.0 (166.0)

[a] Mean (S.D.).

lus by replication, and stimulus by replication by group ($P < 0.005$ or better). Overall, the blindfolded group responded more slowly than the sighted group. Averaged across stimuli and replications, the mean median response time for the blindfolded group was 804.8 ms compared to 588.5 ms for the sighted group. Averaged across groups and replications, the time to respond was similar for the 0.5 and 4 kHz stimuli (747.4 and 719.6 ms, respectively), and comparatively longer than the RT for

the broadband stimulus (622.9 ms). Paired t-tests for the first and last replications for each group indicated that the sighted group showed significant decrements of 120.2 and 148.2 ms ($P < 0.02$ or better) for the 4 kHz and broadband noise stimuli, respectively, and the blindfolded group showed a significant decrement of 410.8 ms ($P < 0.0001$) for the broadband stimulus.

5. Discussion

In line with previously published data [8], overall accuracy in horizontal plane sound localization for a speaker array that surrounded subjects in space was highest when subjects were given access to binaural and spectral cues in combination (the broadband noise) and lowest with only the interaural time of arrival difference cue (0.5 kHz). This was true for both sighted and blindfolded subjects. The sighted group was consistently more accurate than the blindfolded group, in terms of both overall and azimuthal P(C). Both groups improved significantly over the five replications, the sighted group when localizing the 4 kHz stimulus, and the blindfolded group when localizing both the 4 kHz and broadband stimuli. This finding, along with the relatively high proportion of front/back mirror image reversal errors and virtual non-existence of right/left errors, suggests that learning was specific to the encoding of spectral information. The blindfolded group showed greater improvement over replications.

These results provide further support for perceptual learning in sound localization [3,4]. The new finding is that subjects can adapt to the handicapping effects of visual deprivation in the short term. The greater gains made by the blindfolded group and the pattern of improvements are in line with Abel et al.'s finding [1] that individuals who became blind later in life have no difficulty with sound localization and may use binaural and spectral cues in combination to a greater advantage than normal. Also in line with previous findings, sighted subjects were more accurate for speakers on the left than the right side of space. This pattern emerged over time in the blindfolded group. Left-sided superiority in horizontal plane sound localization has previously been shown and has been interpreted as a right cerebral hemisphere advantage for processing spectral information [8,13].

The results also showed that RTs diminished with practice for both groups, although the blindfolded group consistently responded more slowly than the sighted group. Averaged across replications, the differences between the two groups were 171, 245 and 234 ms for the 0.5, 4 kHz and broadband stimuli, respectively. Over replications, the most dramatic decrease in RT was observed for the blindfolded group for the broadband noise. RT decreased by 411 ms from the first to the fifth replication. Since the broadband noise was always presented first, the longer time to respond for the first replication by this group may have been due to problems in finding the response keys. By the fifth replication, the differences in RT between the two groups for the 0.5, 4 kHz and broad band noise stimuli were 150, 173 and 133 ms, respectively, compared with 141, 254 and 396 ms at the first replication. These findings indicate that learning extended to the time to make and signify a judgment

and that the performance of the blindfolded group was approaching that of the sighted group on this measure. The decrease in RT may have been due to the ability to shorten the time to identify the speaker that had emitted the stimulus, an improvement at mapping the sources onto the response keys [20] or a change in response strategy as subjects became more familiar with the experimental paradigm. [21]. Changes in sensory encoding would underlie the first possibility. Changes in non-sensory decision making would underlie the latter two possibilities.

6. Conclusions

1. Blindfolded sighted subjects were relatively less accurate in sound localization than sighted subjects when comparisons were made of either overall P(C) or azimuth P(C), regardless of replication.
2. Both sighted and blindfolded subjects showed gains with practice, the blindfolded group to a greater degree.
3. Increases in accuracy were largely due to improvements in the use of spectral cues.
4. The blindfolded group took longer to respond than the sighted group. Both groups showed decrements in response time with practice, particularly the blindfolded group.

Acknowledgements

This research was supported by funding from Defence Research and Development Canada-Toronto.

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